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ARTICLE

Making climate information useable for forest-based climate change interventions in South Africa

C Ofoegbu [a,b] and Chinwe Ifejika Speranza [a]

[a]Institute of Geography, University of Bern, Bern, Switzerland; [b]Swedish Species Information Centre, Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden

ABSTRACT

Understanding knowledge systems, that is the combination of agents, practices, and institutions that organize the production, transfer, and use of knowledge and their role in making climate information useable for forest-based climate responses, is critical for building resilience to climate change. This study used the concept of a knowledge system to examine how organizational collaboration, in the processes of forecast translation, influences the production of useable information in forest-based climate change interventions in South Africa. Twenty-two key informant interviews were conducted with actors in the fields of climate change and forestry. Results reveal that carbon sequestration and landscape management are the dominant forest-based climate interventions. Consequently, the information translated from the forecasts is tailored towards facilitating the implementation of these two interventions. Network analysis reveals that actors in the categories of small-scale forest companies and community-based enterprises are less integrated into the process of information production. A concerted effort towards the meaningful integration of all categories of actors in the process of information production, as well as the production of information that encourages the implementation of other types of forest-based climate change interventions such as forest bioenergy, is thus recommended.

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KEYWORDS
Climate services; forecasts; knowledge system; network; adaptation; south africa

1.0 Background

In global climate policy processes, the role of forests in mitigating climate change and supporting climate change adaptation is widely acknowledged (Intergovernmental Panel on Climate Change IPCC 2014; FAO 2013; Gullison et al. 2007). Forest management can facilitate climate change mitigation through reducing emissions from deforestation and forest degradation, and enhancement of forest carbon stocks (Locatelli et al. 2015). Similarly, forest management can facilitate climate change adaptation through the provisioning of ecosystem goods and services that people depend on for livelihoods, in the event of climate risks. An example is the case of rural households' dependence on forest ecosystem goods for their livelihoods and income because of crop failure due to drought (Ofoegbu et al. 2017; Milne et al. 2016). Additionally, forests provide vital ecosystem goods and services that are crucial to societal wellbeing (Naidoo, Davis, and Van Garderen 2013). The term forest, as used in this study, includes natural forests, woodlands, and tree plantations. Together, they are a major contributor to the national Gross Domestic Product (GDP), and a key provider of employment in most developing countries (Ofoegbu et al. 2016a; Dlamini 2014). In South Africa, the forestry sector provides direct and indirect employment for between 200,000 and 260,000 people (Ofoegbu et al. 2016a). In many African communities, forests are a significant component of household livelihoods (Chidumayo et al. 2011). Firewood, charcoal, poles, timber, mushrooms, edible insects, weaving fiber, thatch grass, and fodder for livestock are some of the forest resources that have been identified as a major component of household livelihood strategies in most African societies (Ofoegbu et al. 2016a; Chia et al. 2013; Chidumayo et al. 2011).

Although most African countries' climate policies contain mandates for forest-based climate change interventions, they do not provide guidance for adjusting forest management decisions to support the implementation of forest-based climate change interventions. Further, adjustments in forest management to support climate interventions would be impractical without access to climate information (Nhamo 2015; Dlamini 2014; Milimo 2014). Access to relevant and useable climate information will enable forest managers to anticipate, mitigate, and adapt to the risks posed by climate change, while maximizing any opportunities (Soares, Alexandera, and Dessai 2018). The interactions between climate and forest imply that a dramatic change in one will influence the other. This feedback could be negative in some situations and positive in others. Climate change could alter the frequency and intensity of forest disturbances such

CONTACT C Ofoegbu ofoegbu.c@gmail.com

as insect outbreaks, invasive species, wildfires, and storms (Keenan 2015; FAO 2013). These disturbances can reduce forest productivity and change the distribution of tree species. There have been reported cases of climate change impairing the ability of forests to deliver critical ecosystem services, such as timber, berries, mushrooms, and clean water, to the detriment of the livelihoods of forest-dependent communities and forest-based enterprises (Keenan 2015; FAO 2013).

However, the transition from climate forecasts that are broadly useful, to translated and tailored information that is usable in the forestry sector, is a complex process that cuts across sectors, institutional structures, and governance scales (Kalafatis et al. 2015; Harvey and Fisher 2013). The power and influence imbalance among actors in the intersecting field of climate change and forestry can further complicate the process of the translation of climate forecasts into forestry relevant climate information (Borg, Toikka, and Primmer 2015). This imbalance can influence the extent to which an actor's needs and concerns are integrated into the process of climate information co-production, which ultimately affects the relevancy and usability of climate information in the forestry sector.

There is growing recognition of the important role of a collaborative process in facilitating the co-production of relevant and useable climate information for fostering the implementation of forest-based climate change mitigation and adaptation (Harvey and Fisher 2013). However, empirical insight on factors shaping the structure and cohesion of such collaborative networks are rare (Borg, Toikka, and Primmer 2015). In this regard, the concept of a 'knowledge system' has gained traction in various discourses and policy domains (Kalafatis et al. 2015). Whilst there is no one commonly accepted definition of the concept, a knowledge system refers to a combination of agents, practices, and institutions that organize the production, transfer, and use of knowledge. Conceptualizing a knowledge system can provide insights into the components, structure, and cohesion within a network, as well as factors influencing the network towards an intended goal (Kirchhoff, Lemos, and Dessai 2013). We thus apply the concept of a knowledge system to examine how the processes of generating and translating forecasts influence the use of climate information in forest-based climate change interventions.

1.1 Conceptualizing knowledge systems for forest-based climate change interventions

Advances in climate science, especially in the field of climate forecast generation, has played a fundamental role in understanding the risks and potential impacts of climate change on the forestry sector (Kalafatis et al. 2015; Kettle et al. 2014). Nevertheless, it is the collaboration among actors in the forestry and climate change networks that drives the translation and tailoring of climate forecasts into useable information to adjust forest management to support climate change mitigation and adaptation (Kalafatis et al. 2015; Kirchhoff, Lemos, and Dessai 2013; Harvey et al. 2012). The translation of forecasts, as used in this study, refers to the processes involved in the synthesis and transformation of climate forecasts into information useable in forest management decisions. The forecasts of interest are the five timescale forecasts (weather, seasonal, short-term on a scale of 1–5 years, intra-decadal on a scale of 5–10 years, and decadal forecasts) currently being generated and utilized in the South Africa forestry sector.

The concept of a knowledge system, as applied in this study, is adapted from the Global System for Sustainable Development (GSSD) definition (Rlobal System for Sustainable Development (GSSD) 2019, 4) as:

'an organized structure and dynamic process generating types of knowledge, that is characterized by domain-relevant features as defined by the user, reinforced by a set of logical relationships that connect the content of knowledge to its users, enhanced by a set of iterative processes that enable the evolution, revision, and adaptation, and subject to criteria of relevance, reliability, and quality.'

To operationalize the GSSD knowledge system definition in the context of climate forecasts translation and application in forest management, this study focussed on the cross-scale (local, provincial, and national) multi-dimensional collaborations among actors in the interdisciplinary field of forestry and climate change (Figure 1). The relation of collaboration was examined in terms of its influence on:

(a) Forecasts generation and translation activities across scales; and
(b) Feedbacks throughout the process of forecast translation and application in forestry projects.

In order to understand how climate risks and opportunities influence climate information adoption in forestry projects, we explore the nature of the relationships existing among the actors in the knowledge system for forest-based climate change interventions, the extent to which these relationships facilitate iteration and revision, and the actors' demand for forestry relevant climate information. We captured these dimensions in the study´s research questions:

(1) What types of climate information are demanded for forest-based climate change interventions and how are they currently used?
(2) How do the existing structural relationships in inter-organizational collaborations hinder or

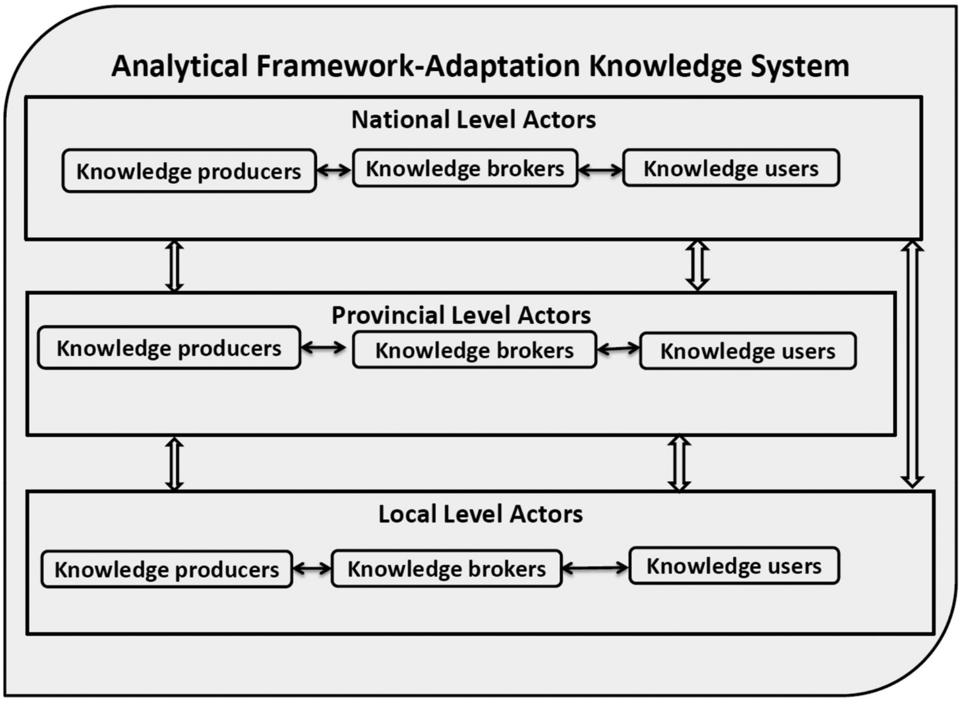

Figure 1. A knowledge system for climate information co-generation. *with respect to the south africa forest sector, examples of knowledge producers include statistics south africa and south africa weather service. examples of knowledge brokers include the department of agriculture fisheries and forestry, and the south africa national biodiversity institute. examples of knowledge users include forest enterprises and community based organisations.*

enhance knowledge flow across scales between national and local levels?

(3) How does knowledge exchange, through organizational networks, hinder or enhance foresters' understanding of climate risks and adaptation?

2.0 Methods

2.1 Description of the study area

The estimated population of South Africa stands at 58.78 million, according to the recently released 2019 mid-year population estimates by Statistics South Africa (Statistics South Africa (Stats SA) 2019). With its total land area of 1 221 037 km2 (122.1 million ha), it is the 25th largest country in the world (Mucina 2018; Lönnstedt 2009). It generally has a temperate climate, due in part to being surrounded by the Atlantic and Indian Oceans on three sides (Government Communication 2016). The climatic zones range from the extreme deserts of the southern Namib in the farthest northwest, to a subtropical climate in the east along the border with Mozambique and the Indian Ocean (Figure 2). The total forest area in South Africa is about 40 million hectares (ha), which is about 7.5% of the country's total land area (Fibre Processing & Manufacturing Sector Education and Training Authority: FP&M SETA, 2014; Department of Agriculture Forestry and Fisheries: DAFF 2010; Lönnstedt 2009). South Africa's forests can be categorized into three main types: Plantations, natural forests, and woodlands (FP&M, 2014).

Natural forests in South Africa cover approximately 0.5 million ha (0.3%) of the country's land area (Mucina and Rutherford 2006). Natural forests are fragmented in scattered patches along the eastern and southern margins (escarpment, mountain ranges and coastal lowlands) of South Africa (Geldenhuys 2002). Common plant species found in the natural forest biome include: *Acacia. Nigrescens, Combretum. Mopane, C. apiculatum, Euclea divinorum, Clerodendrum ternatum, Bothriochloa radicans*, and *Ceratotheca triloba* (Mucina and Rutherford 2006).

Tree plantations in South Africa currently cover an area of roughly 1.487 million ha (Dye 2013; Geldenhuys 2002). Commercial tree plantations are situated in the provinces of KwaZulu Natal, Mpumalanga, Limpopo, Eastern Cape, and Western Cape. Tree plantation industries provide raw materials for downstream forest dependent companies such as pulp milling and paper manufacturing industries, sawmilling industries, and furniture manufacturing industries (Ofoegbu et al. 2016a).

Woodlands are the most accessible forest resource for poor communities and contribute about R2,000 to R5,000 to poor households annually (Shackleton et al. 2007; Dye 2013). Depending on the classification method used, woodlands' coverage in South Africa ranges between 29 and 46 million ha (Dye 2013). Woodlands are valued for their provisioning of

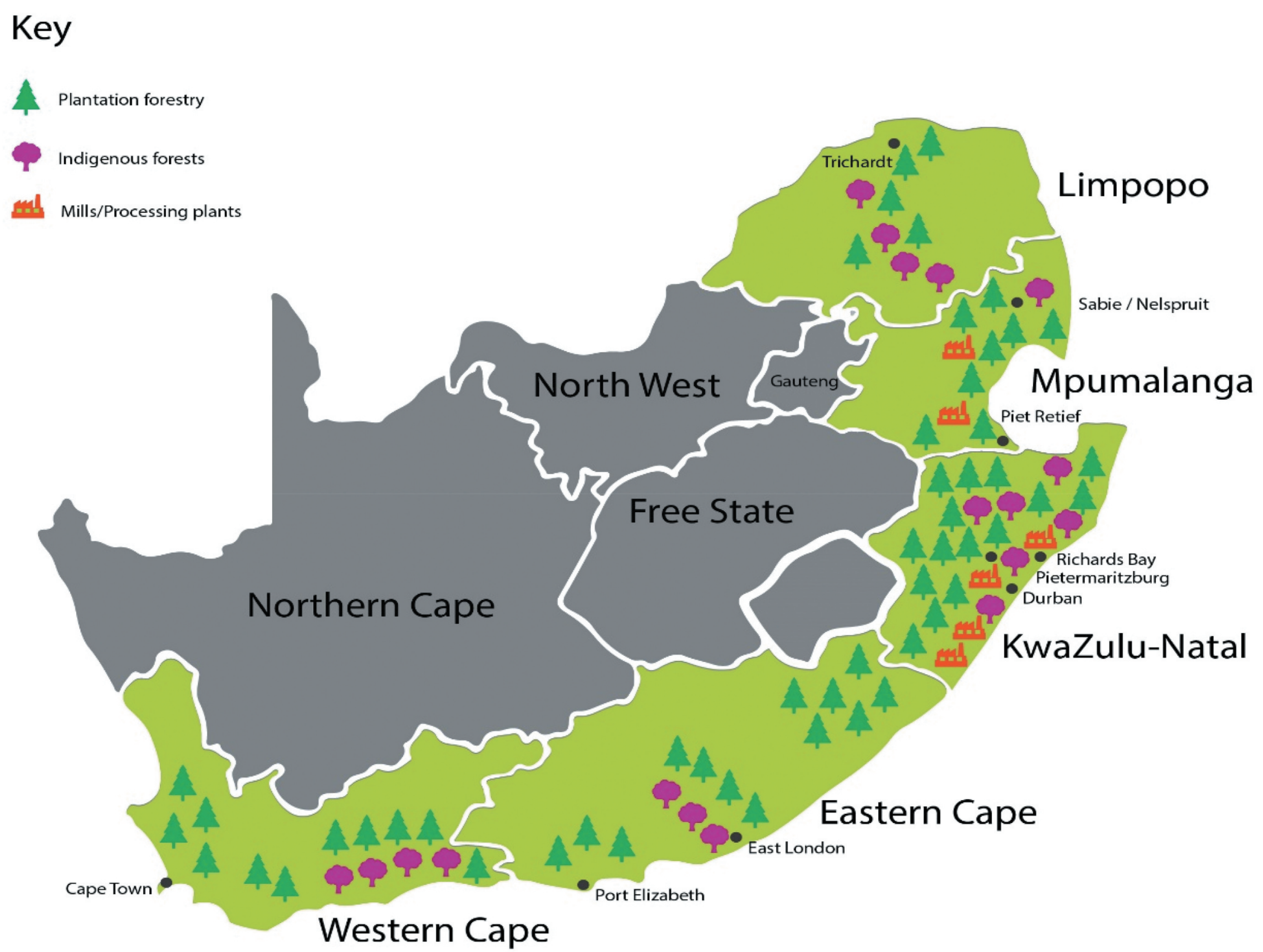

Figure 2. Map of south africa depicting tree plantations, indigenous forests, and timber processing mills (Forestry South Africa: FSA 2021) .

medicinal plants, and for spiritual/cultural values (Shackleton et al. 2013; Shackleton, Shackleton, and Shanley 2011; Mucina and Rutherford 2006).

Climate change is expected to bring considerable warming and drying to much of the country's regions, with greater frequency and intensity of extreme weather events such as heatwaves, flooding and drought (Ziervogel et al. 2014; Warburton and Schulze 2006). There is consensus that the mean annual temperature has increased by at least 1.5 times the observed global average of 0.65°C over the past five decades (Ziervogel et al. 2014). This trend is expected to increase by about 1°C (1.8°F) in parts of South Africa along the coast and to more than 4°C (7.2°F) in the already hot hinterland, such as the Northern Cape in late spring (1 September – 30 November) and summertime (1 December – 28/29 February) by 2050 (Jury 2019; Ziervogel et al. 2014).

The South African forestry sector is sensitive and vulnerable to climate change (Ofoegbu et al. 2017). Under current climatic conditions, only about 1.5% of its land area is suitable for tree crops cultivation, hence a climate change-triggered shift in the optimum tree-growing locations can have a significant impact on the profitability of the forestry sector by 2050 (Warburton and Schulze 2006). The General Circulation Models (GCM) scenario projection of rainfall and temperature patterns over South Africa indicate a potential risk of alteration in the distribution of optimum planting areas for current cultivars of the major tree crop species (e.g., *Pinus patula, Pinus elliottii, Eucalyptus saligna, Eucalyptus nitens, Accacia mearnsii*) grown by tree plantation industries in the country. Therefore, without appropriate risk response management action, there will be a substantial loss of production in the core area of current forestry (Ofoegbu et al. 2016b; Keenan 2015; Kiker 1999). Hence, greater clarity on how climate information can best be integrated into forest management to maximize the mitigation and adaptation benefits of the sector is needed.

2.2 Survey design and data collection

The survey targeted organizational collaborations in the generation and translation of forecasts into climate information useable for management decisions in the forestry sector. The criteria for selection of study participants were based on:

1) The organisation's field of operation (the organisation must be operating in the interface of forestry and climate change with respect to climate information production and use).

2) The organisation's sphere of operation – the organisations sphere of operation should cover any of the national, provincial, and local scales (we purposefully ensured that the interviewed organisations covered all three tiers of governance).

3) The organisation's scale (we purposefully ensured that we interviewed representatives of all six categories of forestry actors in South Africa – Industrial large-scale forest companies, small-scale forest companies, community-based forest enterprises, education/research-based forest enterprises, government departments, and state-owned forest institutions).

Climate information, in the context of this study, is focused on weather and climate forecasts and the associated climate risk warnings and risk response advisory services. Investigated forecasts are based on the following timescales: weather forecasts (days), seasonal forecasts (months), short-term (1–5 yrs), intra-decadal (5–10 yrs), and decadal forecasts (10 years and above). Data collection was based on a literature review and key informant interviews (KIIs) conducted with 22 key informants. The literature search was conducted using the following databases: AGRIS, CAB Abstracts, ISI Web of Science, Scopus, Emerald, and google scholar. We searched for literature using the following search terms [Forest* AND Climate* AND climate services OR climate info*]. The papers collated through the literature search were assessed for inclusion through a multi-tiered process: firstly, based on the title, then by abstract, and finally by full-text review.

The KIIs focused on identifying each organization's network of collaborations in the generation and use of climate information, and the timescale of climate forecasts that the organizations either generate, disseminate, or use in their operations. During the KII, interviewees were asked to list five organizations that their organization collaborates with in sourcing (generation, translation, and communication) climate information. Further questions were asked on 1) the organization's areas of engagement in climate forecast generation, translation and use in forest-based climate change interventions; 2) how climate information was used and the type of forest-based climate change interventions the organization is engaged in, and 3) the type of climate information the organization is able to access and if there are any types of climate information needed, but the organization is not able to access. The KII process enabled the compilation of key actors in the climate information network in South Africa with respect to the forestry sector (Table 1).

2.3 Analysis: operationalizing the conceptualized knowledge system

Data from the key informant interviews were analyzed using both quantitative (network analysis) and qualitative techniques. Data on the collaborations between organizations in the generation and use of climate information were analyzed using network analysis.

Table 1. Names of organisations that made up the climate information production network.

Acronyms	Name of Organisation	Categorization
ARC	Agriculture Research Council	Education/Research Based Institutions
CSIR	Council for Scientific and Industrial Research	Education/Research Based Institutions
DAFF	Department of Agriculture Fisheries and Forestry	Government Departments
DEA	Department of Environmental Affairs	Government Departments
Emtembeni	Emtembeni small-scale timber production	Community Based Enterprise
FPA	Fire Protection Association of South Africa	Community Based Enterprise
FSA	Forestry South Africa	Community Based Enterprise
ICFR	Institute for Commercial Forestry Research	Education/Research Based Institutions
Imvelo	Imvelo Forests (Pty) Ltd	Small Scale Companies
Mondi	Mondi Business South Africa	Industrial Large Scale Companies
LIMA	Lima Rural Development Foundation	Community Based Enterprise
MTO	Mountain To Ocean forestry Group	Small Scale Companies
NCT	NCT Forestry Co-operative	Small Scale Companies
PG Bison	PG Bison Group	Industrial Large Scale Companies
SAFCOL	South African Forestry Companies Limited	State Owned Forest Enterprises
SANBI	South Africa National Biodiversity Institute	Education/Research Based Institutions
SANparks	South African National Parks	Government Departments
SAPPI	South Africa Pulp and Paper Industries Limited	Industrial Large Scale Companies
SAW	South African Weather Service	Government Departments
TWK	TWK Agriculture Holdings	Small Scale Companies
York	York Timbers	Industrial Large Scale Companies
Universities	Universities in South Africa engaged in climate science and forestry research	Education/Research Based Institutions

Using the conceptualized knowledge system as a guide, the data analysis focused on understanding how the structure and cohesion of the collaboration network, among the actors involved in climate forecasts generation and translation, shape the usability/integration of climate information in forest management decisions.

The network analysis aimed at exploring how the structure and cohesion of the collaboration networks act as either an enabler of or barrier to information flows. Respondents' responses were coded as either 1 (presence) or 0 (absence) of a collaboration relation. Network data were analyzed and visualized using UCINET 6.0 and NETDRAW 2.0 software (Borgatti, Everett, and Freeman 2002). The network structure was analyzed using the clustering coefficient, while the network cohesion was analyzed using the density and degree centrality (see Table 3). Degree centrality is useful for identifying an organization's influence in the network (Vance-Borland and Holley 2011). This network data were arranged in an attribute matrix that permitted the categorization of the organizations according to their type (the six categories of forestry-based organisations) and role in the climate information communication network in terms of (a) forecast generation, (b) forecast translation into forestry relevant climate information, and (c) use of climate information in forest-based climate change interventions. Adjacency matrices for each organization and the corresponding attribute files were used to determine the network structure and cohesion (Cornell et al. 2013). An actor with a high in-degree centralization can be characterized as prominent, while an actor with a high out-degree centralization can be characterized as influential (Vance-Borland and Holley 2011).

The measure of clustering coefficient, density, and degree centrality was used to analyze the network structure and cohesion, and its influence on the process of forecast translation and application in forest management actions. As noted by Reffay and Chanier (2003), the cohesion of a network plays a central role in collaborative learning. Thus, analyzing the cohesion of the network will shed light on how the knowledge system, through a reliance on trust and reciprocity, shapes the process of climate forecast generation and translation into forestry relevant climate information; this within the context of shared values and challenges, and equal opportunity (Ifejika Speranza et al. 2018; Moody and Coleman 2015). The analysis of network structure is aimed at uncovering how the relational structure of the organizations in the network acts as either an enabler of, or barrier to, information flow.

Furthermore, data on the type of climate information the organisation uses, how the information is used, gaps in information demand and supply, type of forest-based climate change intervention an organisation is engaged in, were qualitatively analysed. In addition, an organization's areas of engagement in climate forecast generation, translation, and use in forest-based climate change interventions, were also qualitatively analysed. Qualitative data analysis software (NVIVO 11) was used to code and organize the text into themes (Strauss and Corbin 1990). Coding was applied to all transcripts at three levels (Strauss and Corbin 1990): initial/open coding, focused coding, and thematic coding. The transcribed interviews were coded line by line during the initial and open coding until no further new codes emerged

Table 2. Timescale of forecasts used in decision making by forestry actors.

	Investigated Weather and Climate Forecasts				
Actor Category	**Weather**	**Seasonal**	**Short-term (1–5 yrs)**	**Intra-decadal (5–10 yrs)**	**Decadal (10+ yrs)**
Industrial Large Scale Companies	✓	✓	✓	✓	✓
Small Scale Companies	✓	✓	✓	✓	✓
State Owned Forest Enterprises	✓	✓	✓	✓	✓
Government Departments		✓	✓	✓	✓
Community Based Enterprise	✓		✓		
Education/Research Based Institutions	✓	✓	✓	✓	✓

(thematic saturation) (Ofoegbu, New, and Kibet 2018). Coding focused on processes of information production, the content of disseminated information, and the nature of collaborations among the organizations.

3.0 Results

3.1 Climate information usage in forest based climate change interventions

Climate information integration into management decisions is integral to forest management for the actualization of climate change mitigation and adaptation targets. Although various timescales of forecasts, ranging from weather to decadal forecasts, are used in the generation of information on climate risk warning and advisory services for application in forest-based climate change interventions (Table 2), not all categories of actors are equally engaged in this process. As reported by a representative from SANBI – the South African National Biodiversity Institute (one of the interviewed research-based institutions):*'we are not involved in the generation and translation of climate information, our activities are mostly focussed on project implementation. Oftentimes the project has been designed by a third party.'*

Weather forecasts are often used to inform decision-making on forest management operations e.g., when to carry out tree felling operations, when to apply fertilizer, and when to carry out thinning operations. Weather, seasonal, and short-term forecasts are used to inform decision-making on forest maintenance operations e.g., the generation of a fire danger index for appropriate fire management action. The fire index is used for weekly planning of management actions, e.g., fire indices are used for warning, to increase surveillance and to stop management operations that can ignite a fire. This type of forecast use was reported by this category of forestry actors: Industrial large-scale companies, small-scale companies, state-owned forest enterprises, and community-based forest enterprises (see Table 1). Intra-decadal (5–10 yrs), and decadal (10+ yrs) forecasts are used for long term planning of forest management, such as the selection of tree species as regeneration and proactive management strategies aimed at reducing future risks. Generally, actors in the categories of Government departments, and to some extent, education/research-based institutions use intra-decadal and decadal forecasts to design and

Table 3. Forest based climate interventions and associated climate information.

Forest Based Climate Change Interventions	Description	Most mentioned Types of Climate Information Used
Carbon Sequestration	Sustainable forest management and conservation for avoidance of deforestation and degradation	Short-term forecasts of wind speed, temperature, precipitation and humidity are used in management operations e.g. accurate prediction of forest fire risks in order to take appropriate action of fuel load reduction, fire prevention etc., planning of planting operations and forest maintenance operations (e.g. weeding, fertilizer application, pruning, thinning etc.)
Landscape approaches	This describes the application of a landscape approach to afforestation, reforestation and forest landscape restoration	Intra-decadal and decadal forecasts are used to ensure the robustness of management actions to a range of possible future growing conditions by considering species adapted to a range of climate conditions.
Materials substitution with wood products	Substitution of energy-intensive materials with wood products in constructions	Behavioural change
Forest Bioenergy	Substitution of fossil fuels in energy generation e.g. co-firing of wood pellets with coal for bio-electricity production	Behavioural change
Technological approach	Use of genetics and biotechnology for developing resilient forest species	Intra-decadal and decadal forecasts are used in sensitivity analysis to determine plausible scenarios for change in an agro-ecological zone and the subsequent determination/production of tree species suitable for the zone
Sustainable Consumption	Change in traditional consumption patterns through recycle, re-use, and cascade use of forest product e.g. wood	Behavioural change

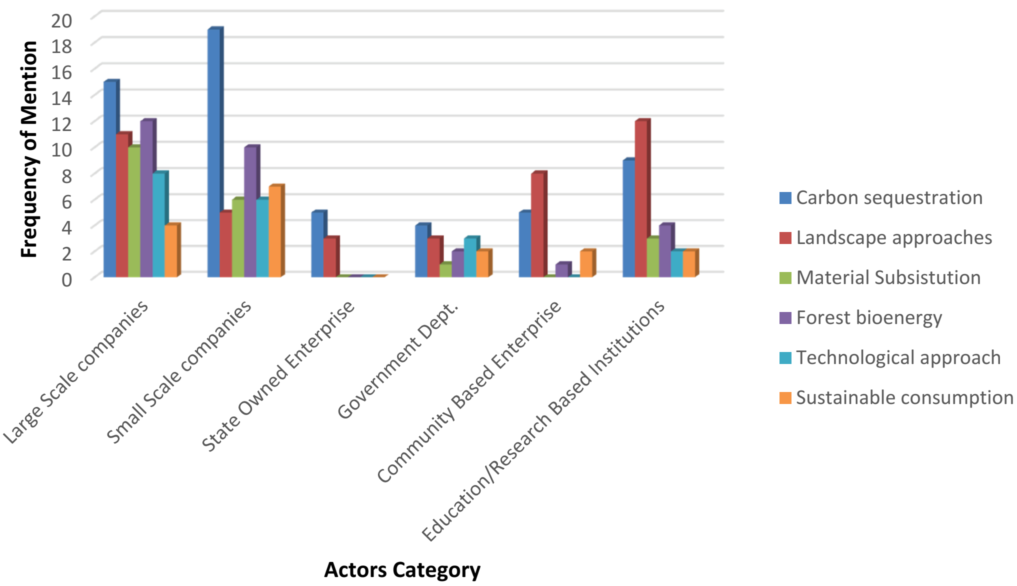

Figure 3. Extent of forest based interventions implementation by different category of actors.

implement projects on biodiversity and forest ecosystems management and conservation, for enhancement of ecological sustainability and resilience to climate risk.

However, as shown in Table 3, the content of the climate information produced from these forecasts and communicated to forestry actors is largely determined by the nature of forest-based climate interventions that the actors are engaged with. The reported forest-based interventions currently being implemented in South Africa can be grouped into six categories (carbon sequestration, landscape approaches, sustainable consumption, forest bioenergy, technological approaches, and material substitution with wood products).

There are differences in the extent to which each category of actor engages in the implementation of these forest-based interventions. As shown in Figure 3, nearly all categories of actors are substantially engaged in carbon sequestration and landscape projects. However, the engagement of state-owned enterprises, community-based enterprises, and government departments, with other types of forest-based interventions (except for carbon sequestration and landscape), is very limited. Hence, climate information disseminated to forestry actors is tailored towards the management of carbon sequestration and landscape projects, which are the dominant types of forest-based interventions in South Africa.

3.2 Actors' participation in forecast generation and translation into forestry relevant climate information

Table 4 presents the participation of actors in the various phases of forecast generation and translation into useable climate information for forest-based climate change interventions. Four phases can be deduced: 1) the forecast production, 2) forecast translation, 3) information integration, and 4) application. The actors participating in the process of climate forecast generation and translation into usable climate information in the forestry sector comprise both forestry and non-forestry actors. Industrial large-scale companies are the dominant category of actors as they participate in all four phases. Although government departments are the main actor category that drives forecast generation and translation (based on policies and legislation), they are, however, less involved in the on-the-ground project implementation (application) phase. The forecast generation phase is dominated by non-forestry actors, which include the South Africa Weather Service (SAWS), one of the main actors

Table 4. Actors and their roles in climate information generation and adoption in forestry action.

		Role in the Forestry Related Climate Information Network			
Actors Category	No of Respondents	Forecast Generation	Forecast Translation	Information Integration	Application in Projects
Industrial Large Scale Companies	5	✓	✓	✓	✓
Small Scale Companies	5	✓	✓		✓
State Owned Forest Enterprises	1	✓		✓	✓
Government Departments	2	✓	✓	✓	
Community Based Enterprise	3			✓	✓
Education/Research Based Institutions	6	✓	✓	✓	

involved in the generation of weather and climate forecasts, and Universities (education/research-based institutions), among others.

All interviewed actors in the industrial large-scale forest company's category are involved in forecast translation into forestry relevant climate information, and its subsequent application in forest management actions. The climate information generated by industrial large-scale companies is generally for organizational use and is rarely disseminated to other forestry stakeholders. The actors in the categories of government departments, and education/research-based institutions are the key actors facilitating the translation of climate forecasts into forestry relevant climate information in South Africa. The climate information translated by these actors is the most publicly available forestry relevant climate information. Although education/research-based institutions (e.g., Universities) are involved in the generation and translation of climate forecasts into forestry relevant climate information, the dissemination of this information to forestry actors, particularly the community-based forest enterprises, and small-scale forest companies, is severely limited due mainly to poor collaboration between these categories of forestry actors. Other research-based institutions (e.g. SANBI), are not strongly engaged in the generation of forestry relevant climate information, but are mostly involved in the execution of projects on forest-based climate change interventions and forest-based adaptation projects e.g., forest conservation. However, other research-based institutions (e.g., ICFR) are involved in the generation of information on climate risk warnings, with respect to forestry. Actors in the category of community-based enterprises are the least represented stakeholders in the climate information communication network. Nonetheless, in a few cases, this category of actors are involved in the execution of forest-based adaptation projects. The fourth phase of climate information application in forestry projects has the least number of participating actors. Thus, there are more actors engaged in the process of generating relevant climate information, than in the actual use of the information on forestry projects for climate change mitigation and adaptation.

3.3 Knowledge system structure and cohesion in the intersecting field of forestry and climate change

The generated network of relations in climate information generation and communication, with respect to forest-based climate change interventions, have a core-periphery fitness score of 0.76, showing that about 76% of the actors that make up the network are situated at the periphery of this network, namely: Emtembeni, MTO, CSIR, Imvelo, SAFCOL, ARC, SANParks, SAPPI, PG Bison, TWK, SANBI, and LIMA. The following organizations were located at the core of the network: FPA, NCT, DAFF, DEA, Mondi, Universities, FSA, ICFR, SAWS, and York (Figure 4). . These organizations are key actors in climate forecast generation, and in the regulation of forest management in South Africa. The DEA and DAFF are, in terms of policy and legislation, the most powerful and influential actors in the regulation of principles, criteria, and indicators of sustainable forestry in South Africa. Thus, the location of DEA and DAFF in the core of the network is an indication of their crucial role in facilitating the generation of forestry relevant climate information. Generally, organizations in the core can coordinate

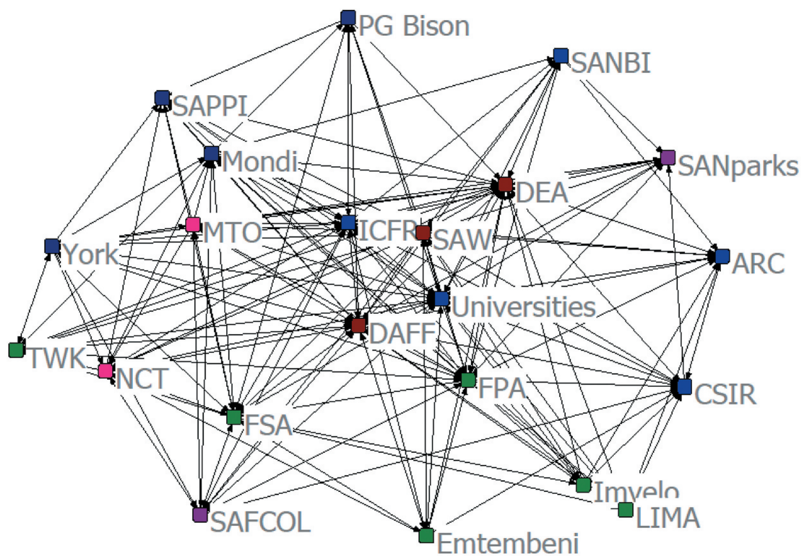

Figure 4. Climate information communication network representing relations among key actors in the intersecting field of forestry and climate change in south africa. *nodes are coloured based on actors categorisation (green: community based forest enterprises, blue: education/research based institutions, pink: small scale forest companies, purple: industrial large scale companies, maroon: government departments). see table 1 for definition of acronym.*

Table 5. Degree centrality and clustering coefficient of organisations in the climate information communication network.

		Degree Centrality		Clustering Coefficient	
SN	Organisations	Degree	n-Degree	Clustering Coefficient (%)	Total Number of Possible Ties
1	ARC	10.000	0.476	0.722	45.000
2	CSIR	12.000	0.571	0.644	66.000
3	DAFF	21.000	1.000	0.474	210.000
4	DEA	19.000	0.905	0.485	171.000
5	Emtembeni	9.000	0.429	0.806	36.000
6	FPA	19.000	0.905	0.532	171.000
7	FSA	16.000	0.762	0.563	120.000
8	ICFR	20.000	0.952	0.508	190.000
9	Imvelo	9.000	0.429	0.819	36.000
10	Mondi	16.000	0.762	0.637	120.000
11	LIMA	9.000	0.429	0.764	36.000
12	MTO	13.000	0.619	0.782	78.000
13	NCT	13.000	0.619	0.763	78.000
14	PG Bison	8.000	0.381	0.929	28.000
15	SAFCOL	11.000	0.524	0.791	55.000
16	SANBI	9.000	0.429	0.833	36.000
17	SANparks	9.000	0.429	0.806	36.000
18	SAPPI	12.000	0.571	0.795	66.000
19	SAW	21.000	1.000	0.483	210.000
20	TWK	10.000	0.476	0.878	45.000
21	York	13.000	0.619	0.795	78.000
22	Universities	21.000	1.000	0.486	210.000

their actions, while those in the periphery are not as easily able to do so, due to the loose connections between them. Consequently, organizations in the core have a structural advantage in exchange relations with organizations in the periphery. The climate information communication network (Figure 4) gives a graphical view of the nature of relationships that exist between the various types of organizations in the climate information production and dissemination landscape with respect to forestry in South Africa.

The analysis of the relations of collaboration in the process of forecast generation and translation into forestry relevant climate information reveals a complex interaction that shapes knowledge flow and communication among the various category of forestry actors. The information communication network has an overall density of 0.522. This means that 52% of all possible ties in the network have been completed. Hence, ample space for improvement in collaboration in climate information production and dissemination among the organizations in the network exists. The network also has an overall clustering coefficient of 0.783; the clustering coefficient gives an indication of how quickly information can spread within the network. Based on degree centrality, DAFF, Universities, SAWS, and DEA were the most influential actors in the generation and dissemination of forestry relevant climate information. The degree centralization gives an indication of the role/influence of each organization in the climate information communication network (Table 5). Not surprisingly, the Department of Environmental Affairs (DEA), which is the government agency with the mandate for climate change issues in the country, and which plays an influential role in climate forecast generation and translation, has one of the highest degree centrality (21). The individual clustering coefficient of the actors in the network, along with their degree centrality, is presented in Table 5. High degree centrality is an indicator of the level of trust.

An important pattern can be observed in Table 5. All the identified key influential actors (DAFF, Universities, SAWS, and DEA) have a low to moderate clustering coefficient, indicating that there is still much that can be done to improve their collaboration rate/frequency with other actors that make up the network.

4.0 Discussion

4.1 Towards the integration of forecasts and climate information into forest management

The integration of climate information into forest management can help foster sustainable forest management practices for climate change mitigation and adaptation; however, doing so requires extensive engagement of all actors in the interdisciplinary field of climate change and forestry (Holmgren 2015; FAO 2013). The concept of a knowledge system in information production relies on equitable and inclusive participation by all members of the network in the process of information production (Kirchhoff, Lemos, and Dessai 2013). Although inclusivity in information production has been achieved to an extent in our case study, as shown by the network clustering coefficient, some categories of actors are not meaningfully represented in the process of climate information production. The findings show that community-based enterprises and small-scale companies tend to be marginalized in the process of climate information generation.

Additionally, the moderate density of the network indicates that collaborations among actors in the process of information production and communication can be improved by about 48%. Thus, in line with the principles of knowledge systems, actions targeted at enhancing collaborations and inclusion of all categories of actors in the process of information production, will be impactful in improving the process of forecast generation and translation into forestry relevant climate information. In addition, there are differences in the timescale of forecasts used by the various forest actors in deriving the climate information integrated into their decision-making. Thus, without concerted efforts to ensure the participation of all categories of forestry actors in the process of forecast production and translation into forestry relevant climate information, the needs and concerns of the less powerful/less influential actors would likely be overlooked; this may result in them being less willing to incorporate climate information in their projects.

Although the network analysis has provided important insights into the nature of collaborations occurring in the process of climate information production, it did not provide insight into the type of climate information flowing through the network. This limitation makes it difficult to infer the type of climate information demanded, and received, by forestry actors. Future research should therefore probe the type of information flowing through the network, and the type of information demanded and received by actors in the network. This will improve the understanding of gaps in demand and provide climate information, as well as convey forestry actors' concerns and perceptions about the reliability, relevance and usability of the climate information being communicated through their network with respect to forest-based climate interventions.

Although there are currently about six types of forest-based interventions (Table 2) in South Africa, the findings from this study indicate that those projects that require societal behavioural changes, currently receive less attention. In this regard, interventions like sustainable consumption that entails reuse and recycling of wood products to promote cascade use, thereby reducing demand for tree harvesting, are yet to be fully maximized. While increasing attention is given to carbon sequestration and landscape restoration projects, there is a need to pay equal attention to other forest-based interventions as a way of maximizing the forestry sector contribution to national climate change mitigation and adaptation targets. Insight from European and Scandinavian countries, where cascaded use of wood has been well promoted, especially in the wood processing and furniture sector, suggests that this type of approach can significantly improve the forestry sector's contributions to climate change mitigation and adaptation (Thonemann and Schumann 2018). In this regard, FAO (2013) advocates for cross-scale action (landscape, regional or national level) and holistic exploration of all segments of the forestry sector (forest industry, tree plantation, indigenous forests, etc.) as a means to maximize the forestry sector's role in climate change mitigation and adaptation. There is thus a need to explore how climate information generation may promote societal/stakeholders' interest in forest-based climate change interventions such as forest bioenergy, sustainable consumption, and material substitution with wood products.

Although carbon sequestration and landscape approaches are the two dominant forest-based climate change interventions currently being implemented in South Africa, as shown in this study, the poor inclusive participation of all categories of forestry actors in the process of forecast translation into forestry relevant climate information, may jeopardize the success of these projects. This is largely because the effectiveness of integrated landscape management approaches is dependent on how well the perspectives, needs, and interests of all stakeholders, including local communities and individual land users, are represented in the decision-making process (Chazdon et al. 2015). This implies that translated climate risk warning and risk response advisory services will have to be tailored towards all levels of decision-making in forest management, while incorporating the concern of all categories of actors (Never 2012; Kadi et al. 2011).

4.2 Collaboration networks and access to climate information

Although no single network structure is optimal for all circumstances (Bodin and Crona 2009), there is consensus that networks that are heterogeneous, have a high density and contain brokers that bridge relationships between groups, are generally more effective for sustainable natural resource management than those without these features (Vance-Borland and Holley 2011). This assumption fits the observed structure of the collaboration network among the actors in forecast generation and translation into forestry relevant climate information in South Africa. The network is heterogeneous and comprises actors of diverse disciplinary backgrounds, including both forestry and non-forestry actors. Organizational diversity within the climate information network plays a key role in facilitating the generation and translation of forecasts into risk warning and risk response advisory service information relevant for adjusting forest management; this is in order to maximize the mitigation and adaptation benefits from the forestry sector. The organizational diversity of the network promotes a transdisciplinary approach to the process of forecast translation into forestry relevant climate information, thereby facilitating the integration of the views and concerns of all stakeholders in the process.

Nearly all the small-scale forest companies and community-based organizations are situated at the periphery of the network. This indicates how detached these organizations are from the activities of climate information generation and integration into forest management in South Africa. In contrast, nearly all the most influential organizations in the network, based on degree centrality, are mostly involved in regulatory work with respect to South African forest policy and regulations. There is therefore a mismatch between participation in climate information generation and active involvement in on-the-ground project implementation of forest-based climate change interventions. This situation may hinder the efficient translation of forecasts into risk warning and risk response advisory services relevant for project implementation by all forestry actors.

Managing the challenge of poor reciprocity in the collaboration between influential actors and other members of the network may facilitate the integration of climate information, especially at the on-the-ground project level. This is because such actions will facilitate small-scale forest companies and community-based forestry organizations' access to context tailored climate information. However, efforts to date have tended to concentrate on improving the underlying scientific observation systems for forecast generation (Harvey and Fisher 2013; Harvey et al. 2012), whilst less attention has been paid to improving the relationship ties among all categories of forestry actors; this is seen as a way of facilitating forestry actors' access to relevant and useable climate information for decision-making (Cornell et al. 2013).

The lack of centrality of small-scale forest companies and community-based forestry organizations in the network suggests that these categories of forestry actors are not yet playing a meaningful role in the process of climate information co-production, with respect to the South African forestry sector. Strengthening the capacity of these categories of forestry actors is thus needed to enhance their participation in the process of forecast production and translation into forestry relevant climate information. This is affirmed by the findings of Stein, Ernstson, and Barron (2011) that initiatives have helped to capacitate and better link otherwise disconnected stakeholders at the local level, to higher levels of governance in the process of information co-production.

The presence of DEA, DAFF, and SAWS as central actors in the communication network is not surprising given their jurisdictional roles in the intersecting field of forestry and climate change in South Africa. However, their low clustering coefficients imply that they are not yet maximally connected to other forestry stakeholders in the network. This situation can have ripple negative impacts on rural livelihoods. When forestry actors, operating at the grassroots level, do not have access to needed climate information, they are unlikely to foster implementation of sustainable forest-based climate change interventions, which can have negative consequences for people's livelihoods and forest enterprises. Adjusting forest management practices for climate change mitigation and adaptation benefit depends heavily on connections and feedbacks among the actors in the network. This is because reflective, collective learning for improving the reliability, relevance, and suitability of climate information to fit the context of all categories of forestry actors, relies heavily on reciprocity and the density of the connections that exist among the actors in the network (Cornell et al. 2013; Never 2012). Considering the collaboration gap between central actors (e.g., DEA, DAFF, and SAWS) and all categories of forestry actors, further research on modalities for improving reciprocity and connectivity in collaborations is needed.

5.0 Conclusion

This study sheds some light on how the structure and cohesion of organizational collaborations affect the translation of climate forecasts into useable climate information, with the aim of fostering the implementation of forest-based climate change interventions. The study is premised on the application of the knowledge system concept, which provides a framework for understanding how collaboration among the actors, within a network, shapes the functioning of that network towards an intended goal. The application of the knowledge system concept in this study provided important insights into how collaboration among the actors in the forestry and climate change field shapes the process of climate forecast translation into relevant and useable climate information for the forestry sector. Although the concept of a knowledge system can provide a framework for understanding this complexity, the knowledge system for forest-based climate change intervention is still relatively new and evolving. In this context, we need to understand how the knowledge system structure and cohesion shape the generation and translation of climate forecasts into relevant and useable climate information; this is necessary for decisions and actions aimed towards the implementation of forest-based climate change interventions.

The process of climate forecast translation into useable climate information for the forestry sector has almost exclusively focussed on the production of climate information relevant for carbon sequestration and landscape management approaches. A gap, therefore, remains in understanding how the knowledge system framework can stimulate the process of forecast generation and translation towards the production of information. This information will facilitate the implementation of other types of forest-based climate change interventions, such as the sustainable consumption, forest bioenergy and material substitution with wood products. The promotion of these types of forest-based climate change interventions will broaden the forestry sector role in South Africa's climate change strategies.

Although organizational collaboration in the process of forecast translation is essential for the production of useable climate information for fostering effective forest-based climate change interventions, fostering collaboration among transdisciplinary actors, and across multiple scales, is a complex ambition characterized by friction. Therefore, creating an enabling environment for collaboration that is iterative, reciprocal, and oriented toward the contextual reality of all categories of forestry stakeholders, across scales from national to the local level, is fundamental to making the generated climate information relevant and useable in forest-based climate change interventions. Additionally, given the poor ratio of central actors to all categories of forestry actors in the network, innovative action will be required from central actors, in order to effectively perform the role of boundary actor in the process of forecast translation into usable climate information in the forestry sector.

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Chidiebere Ofoegbu and Chinwe Ifejika-Speranza authored this study. Both authors participated in (a) conception, design, analysis and interpretation of the data; (b) drafting the article or revising it for important intellectual content; and (c) approval of the final version. All aspects of the data collection process that involved human participants were in accordance with the ethical standards of the University of Cape Town, South Africa. Informed consent was obtained from all individual participants involved in the study. The study received ethical approval from the Faculty of Science Research Ethics Committee, University of Cape Town, South Africa. As at the time of the ethical application and approval, Chidiebere Ofoegbu was an affiliate/employee of the University of Cape Town.

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ORCID

C Ofoegbu http://orcid.org/0000-0002-8920-9411
Chinwe Ifejika Speranza http://orcid.org/0000-0003-1927-7635

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